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Effects of Failure Distribution Considering Various Types of Layout Structure in Automotive Engine Shops

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자동차 엔진공장의 다양한 배치구조형태에서 고장분포가 미치는 영향

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Manufacturing system design poses many challenges for new factory construction. Factories producing the same product may nevertheless have different layouts. The machining line of the engine shop in an automotive factory is a typical flow line, but the layout concept of the line varies among factories. In this paper, a simulation study on the design concept of the manufacturing system for automotive engines is discussed. For comparison, three types of real engine block lines in different factories are analyzed, and three structures of parallel lines are extracted. The effects of failure distribution on the performance measures of three types of parallel line structures are investigated, and some insights are offered regarding the layout concept.

Keywords: Automotive, Engine Shop, Layout Concept, Performance, Failure Distribution

1. Introduction

Developing new manufacturing system designs in automotive factories involves several challenges. First, the overall concept of the layout pattern should be determined, and then various types of machines and material-handling equipment selected. At the same time, operations should be assigned to the machines taking the line balancing into consideration. All these jobs are processed in sequence and many iterative jobs are needed to determine the final design.

The automotive engine consists of five components (camshaft, crankshaft, cylinder block, cylinder head and connecting rod), and the layout of engine shop is highly complex because each part is machined in each sub-line, and many parts are assembled in an assembly line. Although the manufacturing process of automotive engines is very complicated, the process sequences applied in different factories are relatively similar due to the presence of the same main components and manufacturing technology. However, within these similar processes, the layouts of manufacturing lines in different factories are quite dissimilar. These dissimilarities are due to different design concepts regarding how to combine serial and parallel machines (Xu *et al*., 2010).

Nevertheless, the layout concept of each part follows the typical flow line with serial work stations composed of serial or parallel machines. <Figure 1> shows the layout concepts of engine block lines in Korean automotive companies. Type

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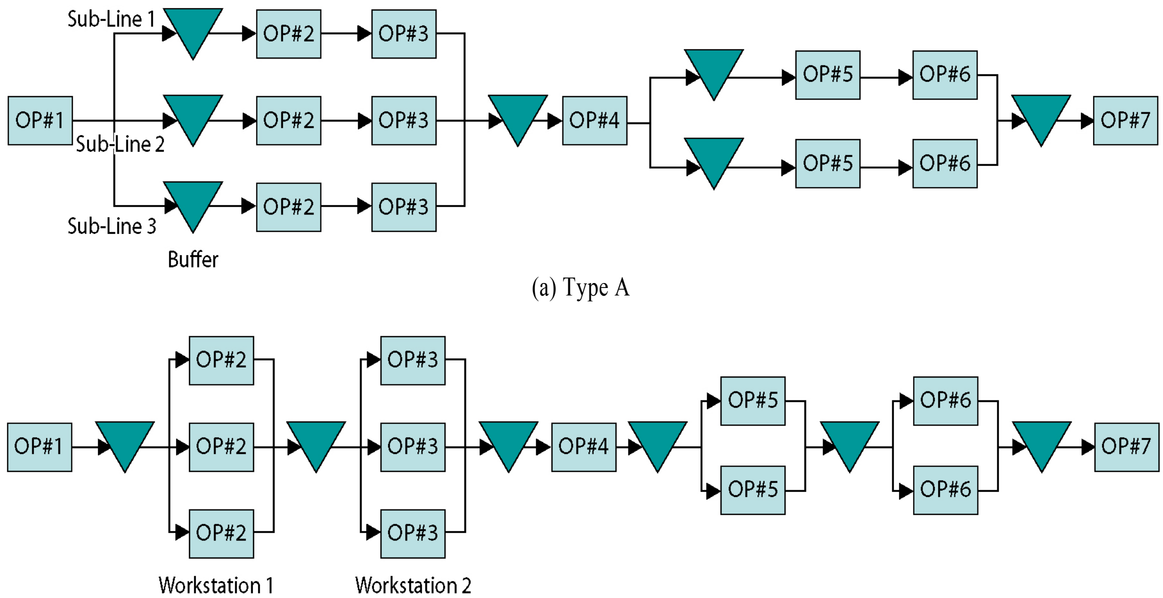


(a) Type A

(b) Type B

Figure 1. Layout Concepts of Engine Block Lines

A adopts parallel sub-lines composed of serial machines. Type B, by contrast, uses serial workstations, and parallel machines are laid out in each workstation. Preferences among layout concepts differ from company to company.

To determine the best design, two methods can be used to analyze the performance of manufacturing systems, namely mathematical analysis and simulation experiment. A great deal of research has been presented to analyze the structure of manufacturing system design using queueing theory, because mathematical modeling is the best method for precise analysis. However, most research has used approximation techniques (e.g. decomposition) because mathematical modeling has limitations when the system is complex. Earlier research regarding the analysis of manufacturing systems (for example, flow line or assembly/disassembly lines) is well addressed in Gershwin (1994), Papadopoulos and Heavey (1996) and Govil and Fu (1999). Magazine and Stecke (1996) considered the problem of improving output rates from un-paced production lines having a fixed process flow and finite buffers by manipulation of the number of work stations, the number of parallel facilities at each work station, the amount of buffer storage between work stations, and the distributions of workload among the stations. Lavantesi *et al*. (2003) presented an efficient analytical method for the performance evaluation of continuous production lines with deterministic processing times, multiple failure modes and finite buffer capacity in a flow line. The discrete flow of parts was approximated by a continuous material flow and each machine can be affected by different failure modes. Tempelmeier and Bűrger (2001) considered an analytical approximation for the performance of non-homogeneous asynchronous flow production systems with finite buffers. In this paper, they assumed generally distributed stochastic processing time as well as breakdowns and imperfect production. Similar work was conducted by Tempelmeier (2003).

For the assembly/disassembly system, Helber (1998) considered tree-type assembly/disassembly network systems of unreliable machines that produce discrete parts. In this paper, stochastic processing times, stochastic MTTF (Mean Times to Failure) and MTTR (Mean Times To Repair), and limited buffer were assumed. Recently, Manitz (2008) proposed a decomposition approach for performance evaluation of assembly lines with both simple processing stations and assembly stations. The general distribution of service time was described by two-moment approximation. Most of the studies described above used simulation to compare the accuracy of analytical methods.

Another approach that has been widely used in analyzing real manufacturing systems that produce automotive engine parts is the simulation. Jayaraman and Agarwal (1996) addressed a general concept of applying the simulation technique to the engine plant. Choi *et al*. (2002) as well as Moon *et al*. (2003) suggested simulation studies regarding engine block lines. Xu *et al*. (2010) compared the performances of three types of layout design concepts in engine block production lines.

In this paper, the effects of the failure distributions of unreliable machines are analyzed by a simulation experiment based on the three basic layout concepts suggested in Xu *et al*. (2010). The latter paper assumed two types of failure modes, but the failure distributions were assumed with exponential distributions. The purpose of the present study is to find the influence of failure distribution functions on the performance of manufacturing systems, for example distribution type, first, second and third moments of MTTF.

2. Concept Design

2.1 General Processes

The cylinder block (or engine block) is the main bottom structure of an engine. The major manufacturing processes of cylinder blocks consist of milling, boring, drilling, washing and taping. As noted above, although the layouts or machines vary from factory to factory, the main process sequences are very similar. Therefore, a standard manufacturing process sequence is abstracted in <Figure 2> by comparing the three types of real manufacturing processes of engine blocks.

2.2 Concept Models

Based on these standard processes, three real cylinder block lines of different Korean factories were compared and analyzed. From this comparison, we found that the three lines adopted a similar structure and work station layout from the first washing operation to the last operation of the processes. The work stations were serially connected and only one machine was set in each station, although of course two or more machines were placed parallel in a station due to differences in target production quantities. Therefore, the only difference in the structures of the work stations was the face milling process. Thus, our research focused on the structure of face milling operations.

After an analysis of the face milling process, six main operations could be established, including main face milling, hole drilling and reaming, front and rear face roughing, fine milling, and so on. In fact, it became clear after the concept models were established that the differences among the three cylinder block lines were the differences in the combination of operations.

<Figure 3> shows the different structures of the face milling process in the three lines. Type A and B are the typical serial and parallel structure production lines, respectively, and type C is a mixed type. We assume that machine 1 of type B includes all operations of machines 1 and 2 of type A. Similarly, machine 3 of type C combines all operations assigned to machines 3 and 4 of type A. Certainly, type B can be extended into many variations with the concept of a parallel system (Xu *et al*., 2010).

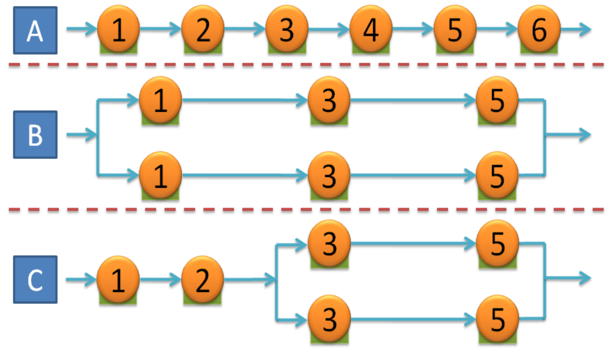


Figure 3. Concept Models of Face Milling Processes

3. Input Data

The cylinder block line considered in this paper is a typical flow line, in which machines are connected by conveyor or gantry carrier. Therefore, there is no buffer or limited buffers between stations. However, if the length of a transfer is long, the buffer size may be assumed as infinite, because the parts of the cylinder block would stay in the transfer before entering the work stations. Therefore, in the experiments, two scenarios will be considered, and they are a line with infinite buffers and one without buffers.

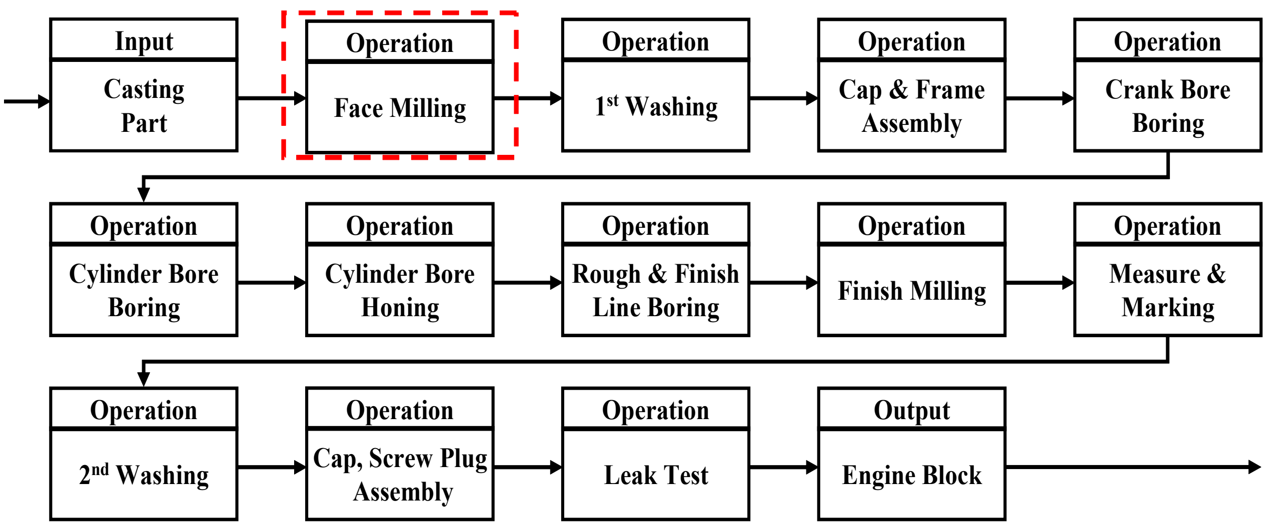


Figure 2. Standard process sequence of engine block

3.1 Cycle Time

We assume that the cycle time of each machine of type A is 60 seconds as assumed in Xu *et al*. (2010). Therefore, the total workload of a face milling station is 360 seconds. In order to make the total workload the same as type A, the cycle time of each machine in type B is set to 120 seconds. Similarly, each cycle time of machines 1 and 2 in type C should be 60 seconds, and the cycle time of machines 3 and 4 should be 120 seconds each. This means that all systems are well balanced or synchronous if there is no failure. The distribution function of the cycle time is assumed as the constant, because this manufacturing system is highly automated. <Table 1> shows the cycle time of each machine.

Table 1. Cycle times of Machines

<table>
<tr><td rowspan="2">Type A</td><td>M1</td><td>M2</td><td>M3</td><td>M4</td><td>M5</td><td>M6</td></tr>
<tr><td>60s</td><td>60s</td><td>60s</td><td>60s</td><td>60s</td><td>60s</td></tr>
<tr><td rowspan="2">Type B</td><td colspan="2">M1</td><td colspan="2">M2</td><td colspan="2">M3</td></tr>
<tr><td colspan="2">120s</td><td colspan="2">120s</td><td colspan="2">120s</td></tr>
<tr><td rowspan="2">Type C</td><td>M1</td><td>M2</td><td colspan="2">M3</td><td colspan="2">M4</td></tr>
<tr><td>60s</td><td>60s</td><td colspan="2">120s</td><td colspan="2">120s</td></tr>
</table>

3.2 Failure Distribution

The main objective of this simulation was to evaluate the effect of failure distribution on the throughput. Although there are many causes of machine breakdown in real world systems, only a single mode of failure was considered. Six kinds of failure distributions were determined as in <Table 2>. The value of MTTF was set to 14,400 seconds (240 minutes) and that of MTTR was set to 600 seconds (10 minutes). Then the average percentage of downtime of each machine was 4% and the theoretical efficiency of each machine was 96%.

$$e = \frac{MTTF}{MTTF + MTTR} = 0.96 \quad (1)$$

The distribution function of MTTR was fixed as EXPO (600) which means exponential distribution with the mean of 600 seconds. Then, six types of MTTF distributions were determined as shown in <Table 2>, where LOGN means log-normal distribution, WEIB means Weibull distribution and H_EXPO denotes hyper-exponential distribution.

To evaluate the effect of failure distribution on performance, eight kinds of distribution functions were selected. Let X be the random variable with the first three moments $E(X^k) = m_k$, $k = 1, 2, 3$. The squared coefficient of variation of X is $CV^2 = \frac{m_2}{m_1^2} - 1$. It is known that the mean queue length depends only on the arrival rate and the first two moments of service time in the M/G/1 queueing system, whereas it depends on the arrival time distribution and service rate in the G/M/c queueing system (Gross and Harris, 1985). It is also reported that the influence of higher moments on the processing time distribution in production lines is moderate (Powell and Pyke, 1994; Lau, 1987). However, the data collected by the field supervisors usually does not include any information concerning the third or any higher moment.

For the effects of failure distribution, we considered two kinds of distribution which are presented for matching the moments of nonnegative random variables such as hyper-exponential distribution of order 2 and Coxian distribution with Erlang node. The hyper-exponential distribution of order 2, denoted by $H_2(p:\gamma_1, \gamma_2)$ or simply H_2, has the probability density function of the form of Equation (2).

$$f(t) = p\gamma_1 e^{-\gamma_1 t} + (1-p)\gamma_2 e^{-\gamma_2 t}, t \geq 0 \quad (2)$$

The parameters p, γ_1 and γ_2 can be determined by the first two moments m_1 and $CV^2 \geq 1$ of X as follows,

Table 2. Moments and Parameters of MTTF Distributions

<table>
<tr><td rowspan="3" colspan="2"></td><td colspan="5">MTTF</td></tr>
<tr><td rowspan="2">Dist</td><td colspan="3">Moments</td><td rowspan="2">Parameters</td></tr>
<tr><td>m_1</td><td>CV^2</td><td>m_3</td></tr>
<tr><td rowspan="3">Group 1</td><td>Case 1</td><td>WEIB</td><td>14400</td><td>0.5</td><td>1.79159×10^{13}</td><td>$\alpha = 1.4355$, $\beta = 15859.0$</td></tr>
<tr><td>Case 2</td><td>ERLA</td><td>14400</td><td>0.5</td><td>2.38879×10^{13}</td><td>$k = 2$, $\mu = 7200$</td></tr>
<tr><td>Case 3</td><td>M_ERLA</td><td>14400</td><td>0.5</td><td>8.68048×10^{12}</td><td>$p = 0.80153$, $k = 3$, $\mu_1 = 5644.48$, $\mu_2 = 1389.61$</td></tr>
<tr><td rowspan="2">Group 2</td><td>Case 4</td><td>EXPO</td><td>14400</td><td>1</td><td>8.95795×10^{12}</td><td>$\mu = 14400$</td></tr>
<tr><td>Case 5</td><td>LOGN</td><td>14400</td><td>1</td><td>8.68048×10^{12}</td><td>$\mu = 14400$, $\sigma = 14400$</td></tr>
<tr><td rowspan="3">Group 3</td><td>Case 6</td><td>WEIB</td><td>14400</td><td>2</td><td>4.90308×10^{13}</td><td>$\alpha = 0.720905$, $\beta = 11689.8$</td></tr>
<tr><td>Case 7</td><td>H_EXPO</td><td>14400</td><td>2</td><td>5.37447×10^{13}</td><td>$p = 0.788675$, $1/\gamma_1 = 9129.2$, $1/\gamma_2 = 34070.8$</td></tr>
<tr><td>Case 8</td><td>H_EXPO</td><td>14400</td><td>2</td><td>4.90308×10^{13}</td><td>$p = 0.658728$, $1/\gamma_1 = 7071.0$, $1/\gamma_2 = 28546.5$</td></tr>
</table>

$$p=\frac{1}{2}\left(1+\sqrt{\frac{CV^2-1}{CV^2+1}}\right),\ \gamma_1=\frac{2p}{m_1},\ \gamma_2=\frac{2(1-p)}{m_1}. \quad (3)$$

The H_2 distribution can also be used for fitting the three moments of nonnegative random variables satisfying $CV^2 \geq 1$ and

$$H=\frac{m_1 m_3}{1.5 m_2^2}>1. \quad (4)$$

In this case, the distribution $H_2(p:\gamma_1,\gamma_2)$ with the pre-assigned moments $m_k,\ k=1,2,3$ is uniquely determined by the parameters (Whitt, 1982).

$$\gamma_{1,2}=\frac{1}{2}\left(a_1\pm\sqrt{a_1^2-4a_2}\right),\ p=\frac{\gamma_1(1-\gamma_2 m_1)}{\gamma_1-\gamma_2}, \quad (5)$$

where

$$a_2=\frac{6m_1^2-3m_2}{\frac{3}{2}m_2^2-m_1 m_3},\ a_1=\frac{1}{m_1}\left(1+\frac{1}{2}m_2 a_2\right). \quad (6)$$

Let $E_k(\mu)$ denote the Erlang distribution of order *k* (ERLA) with the parameter μ. The first two moments of *X* with $\frac{1}{k}\leq CV^2\leq\frac{k^2+4}{4k}$ for $k\geq 1$, can be fitted by the mixture of two Erlang distributions (denoted by M_ERLA or $E_{1,k}(p,\mu)$) with probability density function (Tijms, 1994).

$$f(t)=p\mu e^{-\mu t}+(1-p)\mu^k\frac{t^{k-1}}{(k-1)!}e^{-\mu t},\ t>0 \quad (7)$$

where

$$p=\frac{2kCV^2+(k-2)-\sqrt{k^2+4-4kCV^2}}{2(k-1)(1+CV^2)}, \quad (8)$$

$$\mu=\frac{p+k(1-p)}{m_1}.$$

However, the method in Tjims (1994) can be used only for fitting the first two moments. In order to fit the first three moments of a random variable, we used the mixture of two Erlang distributions (denoted by M_ERLA or $E_k(p,\mu_1,\mu_2)$) with probability density function

$$f(t)=p\mu_1^{k-1}\frac{t^{k-2}}{(k-2)!}e^{-\mu_1 t}+(1-p)\mu_2^k\frac{t^{k-1}}{(k-1)!}e^{-\mu_2 t},\ t\geq 0 \quad (9)$$

where the parameters k, p, μ_1 and μ_2 can be determined by Johnson and Taafe (1989).

Then, eight cases of the distribution functions of MTTF were selected and the values of parameters were set as shown in <Table 2>. <Table 2> also shows how the first moment, the second moment (transformed to *CV*), and the third moment of each case were calculated. Similarly, eight cases of the distribution functions of MTTR were selected, and the values of the parameters and the moments were set, as shown in <Table 3>.

4. Simulation Experiments and Results

The simulation models were developed with Arena™. The following were determined for gathering statistics in simulation experiments. Throughput means the production quantity during a given time interval and it is the most important performance measure in manufacturing system design. The utilization of line means the utilization of the last machine (or average value of the last machines) in each type of layout

Table 3. Moments and Parameters of MTTR Distributions

		MTTR				
		Dist	Moments			Parameters
			m_1	CV^2	m_3	
Group 1	Case 1	WEIB	600	0.5	6.2793×10⁸	α = 1.4355, β = 660.7924
	Case 2	ERLA	600	0.5	6.4800×10⁸	k = 2, μ = 300
	Case 3	M_ERLA	600	0.5	6.2793×10⁸	p = 0.80153, k = 3, μ_1 = 235.1879, μ_2 = 57.9059
Group 2	Case 4	EXPO	600	1	1.2960×10⁹	μ = 600
	Case 5	LOGN	600	1	1.7280×10⁹	μ= 600, σ = 600
Group 3	Case 6	WEIB	600	2	3.5498×10⁹	α = 0.720905, β = 487.076
	Case 7	H_EXPO	600	2	3.8880×10⁹	p = 0.788675, 1/γ_1 = 380.385, 1/γ_2 = 1419.615
	Case 8	H_EXPO	600	2	3.5498×10⁹	p = 0.658728, 1/γ_1 = 294.625, 1/γ_2 = 1189.439

as shown in <Figure 3>, because we assumed that there was no blocking in the last machine(s). We also assumed that a part would be supplied to the first machine whenever it becomes idle. Other performance measures considered were total flow time in the system and work-in-process (WIP).

The simulation run time was set to 3,300,000 seconds and the warm-up period was set to 300,000 seconds. For each scenario, 10 replications were conducted and the average values of statistics were listed.

4.1 Variation in MTTF

<Table 4> shows the average throughputs obtained from the experiments. Within each case, the throughput of each type of line structure was different, and this is consistent with the results of Xu et al. (2010). Lau (1987), Powell and Pyke (1994), and Manitz (2008) have reported that the influence of higher moments (above the second) on the processing time distribution in production lines is moderate, and thus they used only the first and second moments for their analyses. Note that the m_1 and CV^2 of cases 1, 2 and 3 are the same, but the m_3 of case 1 (or case 3) and that of case 2 are different. However, the throughputs of cases 1 and 2 seem to be different. Thus we conducted a t-test and calculated p-values as shown in <Table 5>. If the p-value is greater than 0.05, it is difficult to say that the mean throughputs are different with 95% confidence. Therefore, we can conclude intuitively that the two throughputs are the same. The upper triangle of each type in <Table 5> represents the no buffer case, and the lower triangle represents the infinite buffer case.

The first thing one can observe is that the throughput of type B was the best, followed by type C and then type A for both infinite-buffer and no-buffer cases. The second observation is that the effect of m_3 on the throughput was trivial when CV^2 was the same in no-buffer and infinite-buffer cases. This result is consistent with Lau (1987), Powell and Pyke (1994), and Manitz (2008), although they considered the moments of process time, not those of the MTTR of failure distribution. Thirdly, as the value of CV^2 increased, the throughput tended to decrease for infinite-buffer cases. On the contrary, the average throughput was biggest when CV^2 = 1.0 in the no-buffer cases, which may be due to the random number.

As shown in <Table 4>, the ranges of throughputs for each type of layout are less than 1%. This means that the effect of the second moment of MTTF distribution function is moderate. Thus we do not have to focus on finding the exact distribution function of failure from the real data when throughput is the major concern of system design.

Total flow time is defined as the time interval between the start time on the first machine(s) and the finish time on the last machine(s). <Figure 4> shows the total flow time in the system for all combinations. In both the no buffer and infinite buffer cases, the total flow time of type A was the biggest, that of type B was smallest, and the total flow time had a tendency to increase with the increase of CV^2. This trend was particularly evident in infinite-buffer cases.

Work In Process (WIP) means the total number of parts in the system, but in this paper, the numbers of parts being served in the machines are not included. <Figure 5> shows the behavior of WIP of the infinite-buffer case. As one can see, it was similar to the behavior of total flow time.

Table 4. Throughputs of Experiments(MTTF)

Throughput		Dist	No buffer case			Infinite buffer case		
			Type A	Type B	Type C	Type A	Type B	Type C
Group 1	Case 1	WEIB	39,375	44,311	42,435	47,579	47,812	47,758
	Case 2	ERLA	39,231	44,272	42,344	47,646	47,778	47,729
	Case 3	M_ERLA	39,368	44,336	42,439	47,651	47,804	47,786
Group 2	Case 4	EXPO	39,429	44,356	42,431	47,478	47,775	47,672
	Case 5	LOGN	39,431	44,359	42,489	47,542	47,786	47,667
Group 3	Case 6	WEIB	39,460	44,381	42,525	47,438	47,671	47,559
	Case 7	H_EXPO	39,175	44,216	42,275	47,429	47,667	47,562
	Case 8	H_EXPO	39,119	44,190	42,312	47,268	47,598	47,566
Max			39,460	44,381	42,525	47,651	47,812	47,786
Min			39,119	44,190	42,275	47,268	47,598	47,559
Range			341	191	250	383	214	227
Range(%)			0.86%	0.43%	0.59%	0.80%	0.45%	0.48%

Table 5. Results of *t*-test (*p*-value) for MTTF

(a) Type A

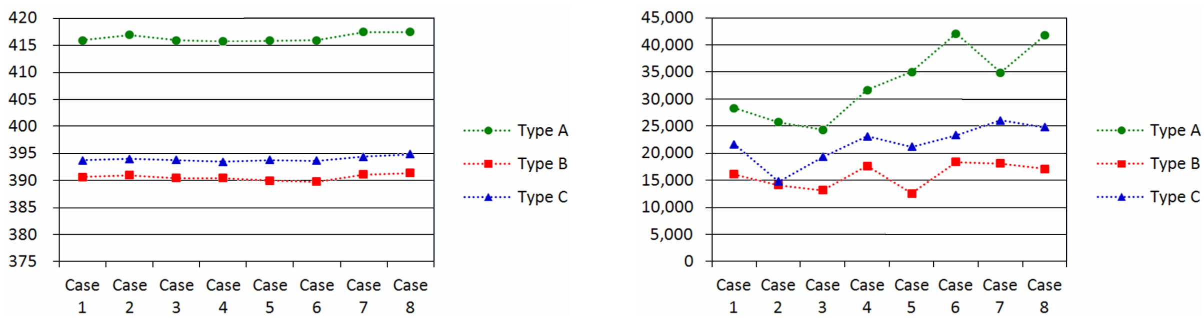
No Buffer		Group 1			Group 2		Group 3		
Infinite Buffer		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Group1	Case 1		0.122	0.444	0.124	0.177	0.163	0.059	0.019
	Case 2	0.119		0.089	0.068	0.093	0.093	0.357	0.224
	Case 3	0.093	0.464		0.148	0.194	0.169	0.097	0.029
Group2	Case 4	0.010	0.005	0.001		0.477	0.314	0.049	0.017
	Case 5	0.234	0.032	0.038	0.107		0.213	0.045	0.014
Group3	Case 6	0.007	0.005	0.002	0.203	0.069		0.039	0.012
	Case 7	0.002	0.000	0.001	0.133	0.001	0.444		0.181
	Case 8	0.000	0.000	0.001	0.014	0.003	0.019	0.023	

(b) Type B

No Buffer		Group 1			Group 2		Group 3		
Infinite Buffer		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Group1	Case 1		0.211	0.178	0.019	0.086	0.069	0.110	0.040
	Case 2	0.109		0.073	0.071	0.100	0.087	0.230	0.128
	Case 3	0.384	0.122		0.321	0.334	0.246	0.080	0.032
Group2	Case 4	0.177	0.473	0.224		0.431	0.194	0.040	0.016
	Case 5	0.090	0.329	0.263	0.376		0.126	0.044	0.020
Group3	Case 6	0.000	0.006	0.004	0.024	0.001		0.028	0.014
	Case 7	0.005	0.010	0.014	0.065	0.010	0.465		0.251
	Case 8	0.000	0.000	0.000	0.003	0.000	0.044	0.085	

(c) Type C

No Buffer		Group 1			Group 2		Group 3		
Infinite Buffer		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Group 1	Case 1		0.130	0.463	0.475	0.225	0.117	0.027	0.044
	Case 2	0.265		0.075	0.158	0.075	0.070	0.270	0.395
	Case 3	0.357	0.131		0.431	0.233	0.147	0.041	0.107
Group 2	Case 4	0.010	0.195	0.116		0.225	0.131	0.101	0.160
	Case 5	0.001	0.074	0.048	0.444		0.195	0.030	0.063
Group 3	Case 6	0.000	0.013	0.010	0.023	0.012		0.023	0.039
	Case 7	0.015	0.021	0.005	0.102	0.088	0.489		0.275
	Case 8	0.022	0.012	0.000	0.129	0.092	0.469	0.478	



(a) No Buffer Case (b) Infinite Buffer Case

Figure 4. Total Flow Time in the System for MTTF

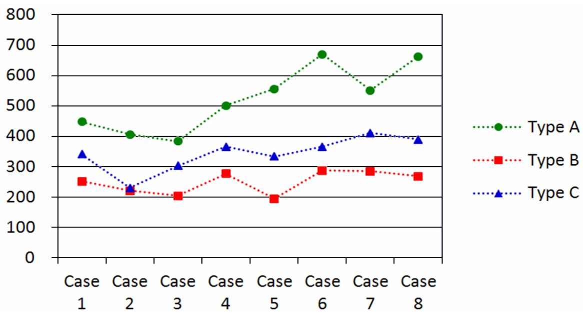


Figure 5. WIP for MTTF

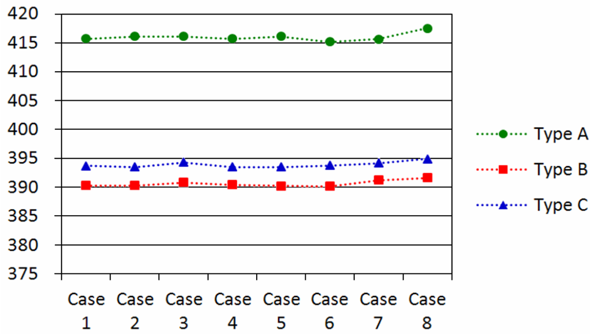
4.2 Variation in MTTR

<Table 6> shows the average throughputs obtained from the experiments when the distribution of MTTR was changed under the assumption that the distribution function of MTTF was fixed as EXPO(14400). The throughput of type B was the best, followed by type C and type A, a result consistent with the case of MTTF in section 5.1. The effects of CV^2 were similar to that in the MTTF case. This means that as the value of CV^2 increases, the throughput tends to decrease in infinite-buffer cases. This observation is definite in infinite-buffer conditions, but not in no-buffer conditions. The results of a t-test as shown in <Table 6> indicate that although the values of the first three moments were the same, the throughputs were different. This was evident in Group 3 ($CV^2 = 2.0$). From this result we can conclude that although the first three moments are the same, the throughput depends on the type of distribution function. This is trivial, however, since the range of maximum and minimum in each type is less than 1% as shown in <Table 6>. In other words, the effects of failure distribution and line structure in infinite-buffer cases are insignificant with respect to throughput.

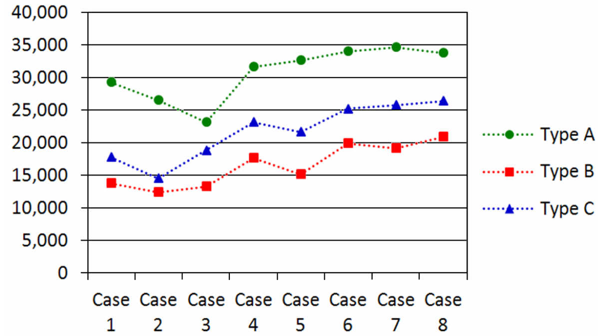
The behaviors of total flow time and WIP were similar to the case of MTTF, as described in section 4.1, increasing with CV^2 as shown in <Figure 6> and <Figure 7>.

Table 6. Throughputs of Experiments (MTTR)

Throughput		Dist	No buffer case			Infinite buffer case		
			Type A	Type B	Type C	Type A	Type B	Type C
Group 1	Case 1	WEIB	39,435	44,356	42,480	47,557	47,794	47,711
	Case 2	ERLA	39,435	44,351	42,443	47,638	47,823	47,772
	Case 3	M_ERLA	39,315	44,247	42,360	47,627	47,785	47,735
Group 2	Case 4	EXPO	39,429	44,356	42,431	47,478	47,775	47,672
	Case 5	LOGN	39,440	44,372	42,452	47,514	47,752	47,672
Group 3	Case 6	WEIB	39,414	44,369	42,528	47,445	47,694	47,692
	Case 7	H_EXPO	39,323	44,200	42,352	47,384	47,631	47,536
	Case 8	H_EXPO	39,131	44,091	42,160	47,322	47,577	47,495
Max			39,440	44,372	42,528	47,638	47,823	47,772
Min			39,131	44,091	42,160	47,322	47,577	47,495
Range			309	281	368	316	246	277
Range(%)			0.78%	0.63%	0.87%	0.66%	0.51%	0.58%



(a) No Buffer Case



(b) Infinite Buffer Case

Figure 6. Total Flow Time in the System for MTTR

Table 7. Results of *t*-test (*p*-value) for MTTR

(a) Type A

Infinite Buffer \ No Buffer		Group 1			Group 2		Group 3		
		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Group 1	Case 1		0.500	0.067	0.428	0.440	0.391	0.075	0.003
	Case 2	0.041		0.037	0.464	0.475	0.428	0.056	0.000
	Case 3	0.061	0.382		0.117	0.097	0.239	0.464	0.026
Group 2	Case 4	0.038	0.001	0.000		0.212	0.386	0.154	0.011
	Case 5	0.185	0.035	0.042	0.257		0.315	0.117	0.008
Group 3	Case 6	0.088	0.014	0.010	0.306	0.162		0.262	0.047
	Case 7	0.014	0.000	0.003	0.082	0.071	0.287		0.008
	Case 8	0.001	0.001	0.000	0.022	0.015	0.101	0.250	

(b) Type B

Infinite Buffer \ No Buffer		Group 1			Group 2		Group 3		
		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Group 1	Case 1		0.426	0.008	0.496	0.186	0.352	0.005	0.001
	Case 2	0.182		0.001	0.453	0.291	0.379	0.002	0.000
	Case 3	0.390	0.063		0.022	0.010	0.043	0.182	0.009
Group 2	Case 4	0.270	0.112	0.417		0.137	0.286	0.011	0.002
	Case 5	0.122	0.066	0.266	0.299		0.434	0.005	0.001
Group 3	Case 6	0.038	0.023	0.099	0.099	0.054		0.016	0.004
	Case 7	0.001	0.000	0.004	0.003	0.023	0.137		0.040
	Case 8	0.000	0.000	0.000	0.001	0.004	0.041	0.142	

(c) Type C

Infinite Buffer \ No Buffer		Group 1			Group 2		Group 3		
		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Group 1	Case 1		0.169	0.003	0.211	0.321	0.278	0.034	0.001
	Case 2	0.065		0.008	0.429	0.440	0.193	0.045	0.000
	Case 3	0.255	0.209		0.197	0.116	0.074	0.450	0.004
Group 2	Case 4	0.210	0.060	0.131		0.283	0.026	0.160	0.008
	Case 5	0.149	0.075	0.127	0.498		0.109	0.072	0.002
Group 3	Case 6	0.329	0.069	0.219	0.270	0.307		0.047	0.005
	Case 7	0.002	0.000	0.000	0.013	0.030	0.005		0.003
	Case 8	0.000	0.000	0.000	0.008	0.009	0.002	0.249	

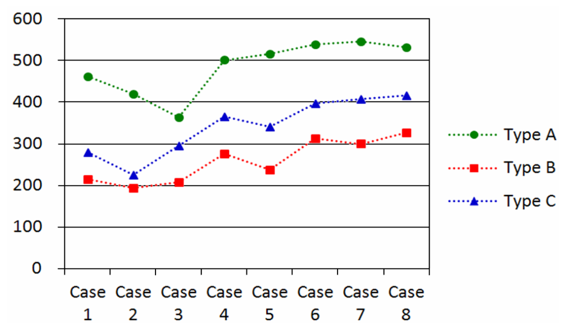


Figure 7. WIP for MTTR

5. Conclusions

This paper discussed a simulation study on the design concept of the manufacturing system for automotive engines. Flow line is a popular layout concept in engine machining shops because engine shops are designed for mass production. Most previous research using queueing theory has considered the basic flow line or assembly/disassembly line. However, it is difficult to find research about which layout concept is better. In practice, the first task in the design phase of a new manufacturing system is to determine the layout concept. We therefore compared three layout concepts in the face milling processes of Korean automotive companies.

When a manufacturing system is analyzed by queueing theory, one of the difficulties lies in the failure distribution, because the Markov property is not satisfied under the general failure distribution function. This is why the approximation method using the first two moments of a distribution function is applied to the analysis. Thus, we considered three types of layout structures and two types of buffer strategies. For each combination, eight kinds of failure distribution were selected considering the first three moments (m_1, CV^2 and m_3) to compare the effects of failure distribution on the performance measures of the system. First, eight distribution functions were applied to the MTTF when the distribution of MTTR was set to EXPO(600). Next, eight distribution functions were applied to the MTTR when the distribution of MTTF was set to EXPO(14,400).

From the simulation experiments, we are able to make some observations. The first is that the type B layout structure was the best, followed by type C and type A, for all performance measures in both infinite-buffer and no-buffer conditions. In this study we assumed that if two processes operated in two machines are united into one, the process time will become twice the original process time (for example, from 60 seconds to 120 seconds). This assumption may not be reasonable in practice, because it is difficult to get a full-balanced job assignment. Thus an economic assessment should be considered when selecting the initial layout concept.

The second observation is that the second moment (CV^2) influences the performance measures. The throughput tended to decrease with the increase of CV^2. Conversely, total flow time and WIP increased with the increase of CV^2. However, the ranges of throughput among the eight cases were less than 1% when the mean values (m_1) of MTTF (or MTTR) were the same. Thus, the effects of CV^2 and m_3 are insignificant in the initial phase of system design if our major concern is the throughput. This observation suggests that the exponential (or hyper-exponential) distribution which is easy to handle can replace other complex distributions for approximating the queueing network model.

For further research, more than two modes of failure should be considered. This will determine the effects of multiple failure distributions on performance. Further analysis will be focused on limited buffer size. Finally, we will attempt to suggest a new approximation method which analyzes the flow line structure more efficiently.

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